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The effects of rosemary extractives and electron beam irradiation on lipid oxidation, color, odor, and flavor of vacuum packaged turkey roll and ham.

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The effects of rosemary extractives and electron beam irradiation on lipid oxidation, color, odor, and flavor of vacuum packaged turkey roll and ham.

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TABLE OF CONTENTS

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CHAPTER 1. GENERAL INTRODUCTION

Introduction

The convenience provided by ready-to-eat meat products has made them one of the most popular meat items in the United States. This increase in popularity and the recent foodborne outbreaks associated with these products have alerted the scientific community. Recently, products such as frankfurters, sliced ham steaks, and lunch meats have been reported and recalled due to contamination with *Listeria monocytogenes* (USDA, FSIS 1998). Although this pathogen is eliminated from ready-to-eat meat products using a proper cooking process (Carlier and others 1996), it can be reintroduced to the finished products during the slicing and packaging processes (Wang and Muriana 1994). Irradiation has been reported to eliminate and/or reduce the population of pathogenic as well as non-pathogenic bacteria from prepackaged foods. This technology enables the food industry to eliminate bacterial contamination from food after processing (Olson 1995). However, there is still the need for information regarding changes in sensory perceptions that might occur if ionizing irradiation treatments are applied to the processed meat products available in today's market.

Thesis Organization

This thesis was written in an alternate style format consisting of four chapters. The first chapter is a general introduction containing an introduction, thesis organization, review of literature, and references cited. The second and third chapters contain two manuscripts to be submitted to the Journal of Food Science. The fourth chapter is a general conclusion that combines the results and discussion sections of both manuscripts.

Review of the Literature

Irradiation

Ionizing radiation refers to a form of radiation that has enough energy to produce positive and negative charges to kill live organisms. Today, this technology has many commercial applications in medical, pharmaceutical, and food operations (Thayer and others 1996). Gamma rays, X rays, and accelerated electrons are the three types of ionizing radiation that can be applied to food (Olson 1998). Gamma rays are obtained from radioactive isotopes such as cobalt-60 or cesium-137 as a result of their natural decay over time (Renwick and Hansen 1996). The energy level emitted by these isotopes has been reported to be about 1 to 2 MeV (Olson 1995). Linear accelerators or Van de Graaff generators can be used to accelerate electrons to energy levels of

10 MeV or more in order to be used for the application of irradiation treatments. Accelerated electrons are transformed into x-rays by making them collide with a film of heavy metal. Today, gamma rays from cobalt-60 and accelerated electrons are the sources of ionizing radiation available for commercial food operations (Olson 1995).

Gamma irradiation is characterized by its ability to penetrate deep into products (Renwick and Hansen 1996). Gamma rays can penetrate 30 cm of water with a radiation energy between 0.15 and 4 MeV (Rosenthal 1992). Gamma irradiation from cobalt-60 is frequently used to irradiate substantial amounts of products. However, products being treated with gamma rays have to be stacked in thick layers in order to be successfully treated. Otherwise, the rays will pass through thin products leaving them untreated. The utilization of this technology often requires processing large quantities of product for a long period of time to obtain a maximum throughput from this type of system (Renwick and Hansen 1996).

X-rays as gamma rays also have a great penetration potential into products. However, the most remarkable difference between the two systems is that x-rays contain a wide range of wavelengths in comparison with the uniform wavelengths emitted by gamma sources (Rosenthal 1992). Also, the production of x-rays leads to an enormous loss of electron beam energy. Only 7 % of the power produced in the electron beam is transformed into x-rays, which makes their production process highly inefficient (Renwick and Hansen 1996).

In order to make use of all the power produced by the e-beam machine, the accelerated electrons have to be applied directly to the food. Unfortunately, these accelerated electrons do not penetrate very deep into the product (Renwick and Hansen 1996). Electron beam irradiation is frequently used for the treatment of surfaces or thin products (Rosenthal 1992). Accelerated electrons can penetrate up to 8.9 cm at 10 MeV in products that have the density of water when using double-sided irradiation (Olson 1995). Electron beam (EB) irradiation seems to be more feasible to treat small amounts of product quickly. This type of technology may allow processors to utilize ionizing radiation for in-line treatments optimizing the utilization of the equipment (Renwick and Hansen 1996).

Regulatory agencies have limited the energy levels that can be emitted by irradiation sources that will be used for the treatment of foods to prevent the production of artificial radioactive substances in the products

(Rosenthal 1992). Gamma ray and x-rays are limited to a maximum energy of 5 MeV, and accelerated electrons produced by machines are limited to a maximum of 10 MeV (Thayer and others 1996).

It is important to determine the irradiation dose that is to be applied to the food during the irradiation process (Olson 1995). The effect of ionizing radiation in the treated product depends on the absorbed dose (Woods and Pikaev 1994). The Gray (Gy) is the unit used to measure radiation doses in the International System of Units. One Gray is equivalent to 1 joule of energy absorbed per kilogram of food (Olson 1995). The irradiation doses applied to food are classified as low dose, lower than 1 kGy, medium dose, 1 to 10 kGy, and high dose, 10 to 50 kGy (Woods and Pikaev 1994). Dosimeters, such as alanine pellets, are recommended to measure the irradiation dose in food because they cover a wide range of doses (10 Gy to 50 kGy) and do not contaminate the product being treated (McLaughlin and others 1989).

Investigators have not found a unique radiolitic product produced by irradiation. The chemical products detected after the irradiation treatment of food are the same formed in products exposed to heat, light, and oxygen (Woods and Pikaev 1994). Irradiation has been applied for many years to a variety of medical and pharmaceutical products including intravenous administration sets, operating room towels, syringes and needles, etc. Irradiation also has been used for the treatment of some consumer products such as cosmetics, baby bottle nipples, and contact lens cleaning solutions (Thayer and others 1996). This technology has a wide variety of applications in the food industry including inhibition of sprouting in vegetables, delay of ripening in fruits, killing insects, pathogenic bacteria and parasites, and extension of shelf life among others (Rosenthal 1992). In the United States, the utilization of irradiation treatments has been approved for wheat and wheat flour, white potatoes, herbs, spices and vegetables seasonings, fruit and vegetables, dehydrated enzymes, animal and pet food, poultry, and trichina inactivation in pork (Thayer and others 1996). More recently, the use of ionizing radiation treatment was approved for refrigerated and frozen uncooked red meats. (USDA, FSIS 1999)

Irradiation of fresh meat

The muscles of healthy animals are sterile. However, their exposure to the environment during the slaughter process provides the microbial contamination frequently present on the surface of the carcasses. Further processing, such as carcass fabrication, spreads bacterial contamination to all exposed meat surfaces (Shay and others 1988). Food borne pathogens such as *Staphylococcus aureus*, *Escherichia coli* O157:H7, and

Listeria monocytogenes may be present in meat and poultry products. Radiation treatments (1.5-10 kGy) can be used to reduce and/or eliminate pathogenic as well as non-pathogenic bacteria (Thayer and others 1996). However, irradiation treatments produce changes in color, flavor, and odor that may reduce the acceptability of irradiated meats (Shay and others 1988). A combination of treatments, such as vacuum packaging and low temperature storage, can be used to minimize these undesirable changes produced by ionizing irradiation (Rosenthal 1992; Olson 1995). For instance, irradiation can be used to eliminate and/or reduce the population of pathogens that might be present in food products, as well as, another tool for the preservation of meat and meat products (Thayer and others 1996).

Pathogens such as *Salmonella*, *Campylobacter* and *Staphylococcus aureus* did not survive 3.0 kGy irradiation dose in fresh, vacuum-packaged pork loins stored at 2 to 4°C (Lebepe and others 1990). Low dose (0.75 to 0.90 kGy) electron beam irradiation reduced approximately 2 logs of *L. monocytogenes* in pork chops. Furthermore, the pathogen was not detected by direct plating or Most Probable Number method when a medium dose (1.8 to 2.0 kGy) was applied to this product (Fu and others 1995). Andrews and others (1995) also found that 10^3 colony-forming units (CFU) of *L. monocytogenes* per milliliter of tryptic soy broth did not survive a 2.0 kGy dose of gamma irradiation. Niemand and others (1981) observed a drastic shift from Gram-negative to Gram-positive types of microorganism in irradiated (2.0 kGy), vacuum packaged beef cuts. Ehioba and others (1988) found similar results in vacuum packaged, ground pork irradiated with a dose of 1.0 kGy and stored at 5°C. An irradiation dose of 3.0 kGy was found to significantly ($P < 0.05$) reduce mesophilic, anaerobic, and facultative-anaerobic microorganism in vacuum packaged pork loins (Lebepe and others 1990).

Irradiation of meat product might be limited by several factors that affect the product's flavor, color, and odor (Shay and others 1988). Free radicals produced during irradiation treatments and their reaction with food may lead to changes in the color, flavor, and odor in the product being treated. The production of these free radicals has been associated with the reaction of ionizing radiation and water (Proctor and others 1952). These radicals can yield lipid radicals via free radical reactions and/or hydroperoxides in the presence of oxygen (Thakur and Singh 1994). Ionizing radiation treatments have been reported to promote the formation of peroxides when oxygen is around and/or within the food (Lee and others 1996). These peroxides subsequently deteriorate into a variety of compounds such as alkanes, alkenes, aldehydes, and alcohols during further

reactions (Patterson and Stevenson 1995). The extent of the changes produced by ionizing irradiation may vary depending on the food being treated, the dose being applied, and the processing techniques being used (Proctor and others 1952).

Investigators agree that the presence of oxygen during the irradiation process increases color deterioration in fresh meat (Urbain 1986; Shay and others 1988; Lambert and others 1992; Lefebvre and others 1994). This type of discoloration has been attributed to the production of brown metmyoglobin and the destruction of the porphyrin ring that yields to formation of a green color (Groninger and others 1956). Modified atmosphere packaging (MAP), such as vacuum or carbon dioxide (CO_2), resulted in the production of a more desirable color in irradiated (1.75 kGy) pork chops (Grant and Patterson 1991). Fresh meat treated under modified atmosphere showed a conversion of the brown metmyoglobin to the desirable pink color of oxymyoglobin (Groninger others 1956).

Irradiation treatments (0.0-10.5 kGy) did not affect the CIE L* (lightness) values of fresh, vacuum packed beef steaks, boneless pork chops, or turkey breasts (Nanke and others 1998). On the contrary, Lambert and others (1992) reported that the L* values of irradiated (0.0-1.0 kGy) pork were higher than the L* values of the control. Zhao and others (1996) reported that irradiated fresh pork generally has higher L* values than non-irradiated pork. Lebepe and others (1990) reported that Hunter a* (redness) values were higher in irradiated, vacuum packaged pork loins than not irradiated loins. Nanke and others (1998) reported a significant increase in a* values as the irradiation dose was increased from 0.0 kGy to 10.5 kGy in vacuum packed pork and from 0.0 kGy to 4.5 kGy in vacuum packed turkey. Lynch and others (1991) reported that irradiated (2.5 kGy), vacuum packaged, raw turkey fillets had a more desirable pink color than the control when evaluated by a sensory panel. An increase in the b* (yellowness) values of irradiated pork was observed as the irradiation dose was increased from 0.0 kGy to 4.5 kGy. The same changes in b* values were observed in irradiated turkey when the doses were increased from 0.0 kGy up to 7.5 kGy (Nanke and others 1998). Lambert and others (1992) observed similar changes in b* values in irradiated (0.5-1.0 kGy) pork loins packaged in a 100% nitrogen (N_2) modified atmosphere. On the other hand, Fu and others (1995) did not find differences in b* values in irradiated (0.75-1.98 kGy) vacuum packaged pork chops.

Some of the undesirable color changes in meat products and the initial stages of lipid oxidation are interrelated. The greater proportion of unsaturated to saturated fatty acids found in pork and turkey and their liability to lipid oxidation may explain the relationship between lipid oxidation and color oxidation in these species (Akamittath and others 1990). The oxidation of fat has been found to be accelerated by gamma irradiation (Lea and others 1960). Groninger and others (1956) reported that the peroxide values of irradiated ground pork increased as the irradiation doses were increased. Lefebvre and others (1994) observed similar results in ground beef. Zhao and others (1996) reported that the TBARS values of irradiated (1.0 kGy), vacuum packaged pork chops were significantly higher ($P < 0.05$) than the control. Mattison and others (1986) and Lambert and others (1992) reported that irradiation (1.0 kGy) did not affect the TBARS values of vacuum packed pork loins. An irradiation dose of 2.5 kGy did not increase the TBARS values of vacuum packaged, raw turkey breast patties stored at 4°C (Ahn and others 1997).

Significant changes in meat flavor and aroma have been reported even at irradiation doses as low as 2.0 kGy (Shay and others 1988). Off-odors produced during the irradiation treatment of fresh meats might be associated with the possible production of volatile sulfur compounds from glutathione and proteins containing sulfhydryl groups (Batzer and Doty 1955). Ahn and others (2000) hypothesized that the off-odors produced in irradiated meats are the result of the radiolitic breakdown of sulfur containing amino acids. Dimethyltrisulphide was reported to be the main sulfur containing compound present in raw chicken meat treated with a medium dose (2.5 kGy) of ionizing irradiation (Patterson and Stevenson 1995). Grant and Patterson (1991) reported that the odor of irradiated pork changed from a "burnt" odor to a "dairy" odor during storage due to the proliferation of lactic acid bacteria in a modified atmosphere package. Lynch and others (1991) reported that turkey fillets treated with irradiation (2.5 kGy) developed an objectionable odor that increased after 21 days of storage according to a trained sensory panel. An irradiation "threshold" dose for organoleptic changes in fresh pork and turkey irradiated at 5 to 10°C has been reported to be about 1.75 kGy (Urbain 1986; Grant and Patterson 1991), and 1.50 kGy (Urbain 1986), respectively.

Irradiation of processed meat

The heat treatments typically used by the meat industry in the production of ready-to-eat meat products provide the bacterial reduction necessary to ensure the wholesomeness of these products. However, pathogens

such as *Listeria monocytogenes* had been detected in ready-to-eat meat products at retail stores. Pathogenic as well as non-pathogenic bacteria can be reintroduced to cooked products during the slicing and packaging processes (Wang and Muriana 1994). Studies on high dose irradiation treatments demonstrated the efficacy of ionizing irradiation to eliminate bacterial contamination in processed meats (Anellis and others 1972; Baburt and others 1987; Crawford and Ruff 1996). The United States Army successfully developed irradiated canned products such as ham, chicken, and turkey (WHO 1994). However, other studies focused on radappertization (sterilization by irradiation) of canned meats reported significant changes in the sensory characteristics of irradiated meat products (Groninger and others 1956; Shults and others 1977a, Shults and others 1977b). Today, the incidence of foodborne outbreaks associated with processed meats have stimulated the scientific community to look at low and medium doses of ionizing radiation as a possible tool for the elimination of pathogenic bacteria from pre-packaged product such as ready-to-eat meats (Olson 1995).

Patterson (1989) reported that *Listeria monocytogenes* can be eliminated from poultry mince meat using medium (2.5-7.0 kGy) irradiation doses. Fu and others (1995) reported that a medium dose (1.8-2.0 kGy) of electron beam irradiation produced a substantial reduction of *L. monocytogenes* in cured hams, but some cells were able to recover after the temperature of the product was increased from 7 to 25°C to simulate product mishandling. Thayer and others (1998) observed a higher decimal reduction values for *Listeria monocytogenes* in pre-cooked irradiated (3.0 kGy) turkey nuggets than in raw, irradiated turkey nuggets.

Gamma radiation (32 kGy) was found to decrease the cured color intensity of ham (Kamarei and others 1981). Shuts and others (1977a) reported that as the irradiation dose increased from 2.5 to 4.5 megarad (25-45 kGy) the discoloration rating increased in corned beef briskets. Groninger and others (1956) observed a significant reduction in the color of irradiated cured hams after a dose of 2.0 megarep (20 kGy) of gamma radiation was applied to the product. However, a medium dose (1.8-2.0 kGy) of ionizing irradiation did not affect the color of vacuum packaged ham stored at 2-4°C (Fu and others 1995).

The lipid oxidation process in cured meats has been reported to be lower than in cooked meats as long as the meat pigment is in the ferrous state (Love and Pearson 1971). Upon storage, the color of cured meat is converted to metmyoglobin and the lipid oxidation is accelerated (Younathan and Watts 1959). Terrell and others (1981) observed an increase in the TBARS values of irradiated frankfurters when the irradiation doses

were increased from 0.0 to 3.2 megarad (0.0-32 kGy). Ahn and others (1998) reported that the TBARS values of irradiated (2.5 kGy) and then cooked turkey breast patties were not affected by the irradiation treatment. Similar results were found by Shults and others (1977a) in irradiated (25-45 kGy) corned beef briskets. Shults and others (1977b) observed lower TBARS values in irradiated (30-60 kGy) canned pork rolls when compared with the control.

Changes in sensory perceptions of irradiated (5.0 kGy) hams were found to be ($P < 0.1$) unacceptable by a group of volunteer families in a consumer acceptability test in Denmark. The participants detected ($P < 0.1$) odors and flavors not normally associated with ham in the irradiated samples (Hansen 1966). A non-characteristic odor was detected in sliced ham and bologna irradiated at doses between 2×10^5 to 2×10^6 rep (2.0-20 kGy) in an aerobic environment. The odor of the ham did not change upon storage, however, the bologna developed a rancid odor after 7 days of storage (Erdman and Watts 1957). Irradiated (32 kGy) frankfurters were found to have a strong off-flavor and a significant reduction ($P < 0.05$) in their overall palatability when compared with the control (Terrell and others 1981). The odor of irradiated and then cooked chicken thighs was found to be affected after a dose of 2.0 kGy was applied to the product. The same study revealed that irradiation treatments up to 3.0 kGy have no detrimental effects on the odor of chicken breast cooked up to 85°C (Heath and others 1990).

The production of volatile compounds and the TBARS values of cooked turkey meat have been shown to be correlated. The concentration of aldehydes such as propanal, pentanal, and hexanal have been reported to be higher in irradiated (2.5 kGy) and then cooked turkey meat stored for 7 days at 4°C (Ahn and others 1998). Also, an increase in the amount of carbonyl compounds was observed in pre-cooked, irradiated (18.6-27.9 kGy), canned pork chops and veal shoulder clods stored at 2°C. The same study revealed that the cooking process increases the concentration of carbonyls and hydrogen sulfides followed by a further increase as a result of the irradiation treatment (Pearson and others 1959). Ahn and others (1998) stated that hexanal and the total volatile content of cooked meat can be used to assess the degree of lipid oxidation in irradiated cooked meat.

Natural antioxidant (rosemary)

The addition of certain aromatic herbs and spices to lipid-containing products to delay their oxidation process has been known for many years (Chipault and others 1952). Rosemary has shown to have considerable

antioxidant activity in both animal fats and vegetable oils (Chang and others 1977). Some of the antioxidant compounds of rosemary have been identified as carnosic acid, carnosol, carnosolic acid, rosmaridipherol, and rosmarinic acid (Löliger 1991). Today, new extracts with high efficacy at low dosage levels are being developed to minimize the changes produced by rosemary in the aroma and color of the treated product (López-Sebastián and others 1998).

The mechanism of action of the antioxidants, both natural and synthetic, is associated with their ability to donate hydrogen atoms to radical species in order to delay the rate of oxidation (Löliger 1991). Bracco and others (1981) concluded that the antioxidant activity of rosemary extracts is primarily related to its carnosic acid and carnosol content. Some of the antioxidant components found in rosemary extracts were reported to be thermally unstable at temperatures of 100°C and above. However, the products formed during this thermal degradation showed active antioxidant properties (Schwarz and others 1992). The higher antioxidant activity of carnosic acid was detected at temperatures of 110°C using a Rancimat test (Hopia and others 1996). Frankel and others (1996) found a higher antioxidant activity of carnosic acid and carnosol at pH 4 and 5 than at pH 7 in a phosphate buffer in corn oil-in-water emulsion.

Rosemary extracts were found to be significantly ($P < 0.05$) effective in preventing the formation of TBARS reactive substances in soybean oil samples containing 0.1 gram of rosemary extract per kilogram of oil (Basaga and others 1997). Rosemary powder (0.1 g of rosemary powder per each gram of fatty acid) was found to protect arachidonic and linoleic acids from gamma-radiolysis induced by irradiation of the lipid samples at doses below 10 kGy (Lacroix and others 1997). Successful antioxidant applications of rosemary were reported in meat products such as turkey sausages (Barbut and others 1985) and restructured chicken nuggets (Lai and others 1991). Barbut and others (1985) reported that the addition of rosemary oleoresin (20 ppm, based on the meat content) to turkey sausages produced a considerable reduction in TBARS values over a 15 days storage period at 4°C. Lai and others (1991) found a significant ($P < 0.01$) linear reduction in TBARS values at each test day in restructured chicken nuggets stored at 4°C as the concentration of oleoresin rosemary was increased from 0.0 to 0.1% of the total weight of the meat. On the contrary, Stoick and others (1991) observed no significant antioxidant activity in restructured beef steaks treated with oleoresin rosemary alone or in combination with sodium tripolyphosphate during refrigerated storage. Liu and others (1992) reported that the

combination of oleoresin rosemary and sodium tripolyphosphate did not slow down lipid oxidation in restructured pork steaks stored at 4°C.

Combination treatments

Combination treatments may help to prevent or reduce the production of undesirable changes in sensory perceptions resulting from the irradiation process (Niemand and others 1981). For example, irradiation under vacuum conditions may reduce the production of radiolytic products (Grant and Patterson 1991). The application of irradiation treatments at low temperatures (0 to –30 ± 10°C) was found to reduce the levels of discoloration of irradiated corned beef briskets at doses of 25 and 35 kGy (Shults and others 1977a). The addition of salt, nitrite, sodium ascorbate, and liquid smoke resulted in a more acceptable odor and color of ground beef and pork after irradiation and subsequent storage for 50 days. Ascorbic acid has been reported to improve both color and odor of irradiated cured meats. The combination of 2 % nitrite with 0.22 % sodium ascorbate in a dip solution provided some protection to ham and bologna slices during irradiation and up to 8 days of storage (Erdman and Watts 1957). The addition of ascorbate in combination with nitrite may provide some protection against undesirable odor and color changes induced by irradiation; however, ascorbate may induce lipid oxidation over long storage periods (Erdman and Watts 1957).

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CHAPTER 2. THE EFFECTS OF ROSEMARY EXTRACTIVES AND ELECTRON BEAM IRRADIATION ON LIPID OXIDATION, COLOR, ODOR, AND FLAVOR OF VACUUM PACKAGED TURKEY ROLL

A paper to be submitted to the Journal of Food Science

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Abstract

The effect of irradiation treatments (0.0-3.2 kGy), in combination with rosemary extractives, on lipid oxidation (TBARS), color (CIE L*, a*, and b*), odor, and flavor of vacuum packaged turkey rolls stored at 2-4°C for 60 days were studied. A sensory evaluation was performed to determine differences in color, off-odor, off-flavor, and overall flavor intensities of cold and reheated turkey rolls. Rosemary significantly ($P < 0.05$) reduced the TBARS values of the turkey rolls. Irradiation showed no effect on the TBARS values. A trained sensory panel detected differences in color, off-odor, and off-flavor intensities of the cold turkey rolls. Heat did not decrease the off-odor and off-flavor of the irradiated turkey rolls.

Introduction

Recently, products such as frankfurters, sliced ham steaks, and lunch meats have been reported and recalled due to contamination with *Listeria monocytogenes* (USDA, FSIS 1998). Although this pathogen is eliminated from ready-to-eat meat products using a proper thermal process (Carlier and others 1996), it can be reintroduced to the finished products during the slicing and packaging processes (Wang and Muriana 1994). The safety of these products cannot be assured by low storage temperature (Palumbo 1986). Low storage temperature may slow down the metabolism of the bacteria responsible for the product deterioration, however, it does not prevent the growth of pathogens such as *Listeria monocytogenes* once recontamination occurs (Beumer and others 1996). Studies have demonstrated the efficacy of ionizing irradiation for the elimination of pathogenic bacteria from pre-cooked meats (Thayer and others 1998; Fu and others 1995).

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However some studies which focused on radappertization of canned meats, reported significant changes in the sensory characteristics of irradiated meat products (Groninger and others 1956; Shults and others 1977a; Shults and others 1977b).

Free radicals produced during irradiation treatments and their reaction with food may lead to changes in the color, flavor and odor in the product being treated. The extent of the changes produced by ionizing irradiation may vary depending on the food being treated, the irradiation dose being applied, and the processing techniques being used (Proctor and others 1952). The oxidation of fat, one of the primary mechanisms of food deterioration, has been found to be accelerated by gamma irradiation (Lea and others 1960). Groninger and others (1956) reported that the peroxide values of irradiated ground pork increased as the irradiation doses were increased. Lefebvre and others (1994) observed similar results in ground beef. Zhao and others (1996) reported that the TBARS values of irradiated (1.0 kGy), vacuum packaged pork chops were significantly higher ($P < 0.05$) than the control. On the other hand, Mattison and others (1986) and Lambert and others (1992) reported that irradiation (1.0 kGy) did not affect the TBARS values of vacuum packaged pork loins. Ahn and others (1998) reported that the TBARS values of irradiated (2.5 kGy) and then cooked turkey breast patties were not affected by the irradiation treatment. Similar results were found by Shults and others (1977a) in irradiated (25-45 kGy) corned beef briskets. Shults and others (1977b) observed lower TBARS values in irradiated (30-60 kGy) canned pork rolls when compared with the control.

Investigators agreed that the presence of oxygen during the irradiation process increases color deterioration in fresh meat (Urbain 1986; Shay and others 1988; Lambert and others 1992; Lefebvre and others 1994). Modified atmosphere packaging such as vacuum or carbon dioxide (CO_2) resulted in the production of a more desirable color in irradiated (1.75 kGy) pork chops (Grant and Patterson 1991; Lefebvre and others 1994). An increase in pinkness was observed by Nanke and others (1998) in vacuum packaged, fresh turkey meat as the irradiation doses were increased from 0.0-4.5 kGy.

Significant changes in meat flavor and aroma have been reported even at irradiation doses as low as 2.0 kGy (Shay and others 1988). A group of volunteer families detected differences ($P < 0.1$) in flavor of irradiated (5.0 kGy) ham in a consumer test performed in Denmark (Hansen 1966). Irradiated (32 kGy) frankfurters were found to have a strong off-flavor and a significant ($P < 0.05$) reduction in their overall palatability when

compared with the control (Terrell and others 1981). A non-characteristic odor was detected in sliced ham and bologna irradiated at doses between 2 x 10^5 to 2 x 10^6 rep (2.0-20 kGy) in an aerobic environment (Erdman and Watts 1957). The odor of the ham did not change upon storage; however, the bologna developed a rancid odor after 7 days of storage (Erdman and Watts 1957). The odor of irradiated and then cooked chicken thighs was found to be affected after a dose of 2.0 kGy was applied to the product. The same study revealed that irradiation treatments up to 3.0 kGy have no detrimental effects on the odor of chicken breast cooked up to 85°C (Heath and others 1990). Lynch and others (1991) reported that turkey fillets treated with irradiation (2.5 kGy) developed an objectionable odor that increased after 21 days of storage.

Off-odors produced during the irradiation treatment of fresh meats might be associated with the possible production of volatile sulfur compound from glutathione and proteins containing sulfhydryl groups (Batzer and Doty 1955). Ahn and others (2000) hypothesized that the off-odors produced in irradiated meats are the result of the radiolitic breakdown of sulfur containing amino acids. Grant and Patterson (1991) reported that the odor of irradiated pork changed from a "burnt" odor to a "dairy" odor during storage due to the proliferation of lactic acid bacteria in a modified atmosphere package. An irradiation "threshold" dose for organoleptic changes in fresh pork and turkey irradiated at 5 to 10°C has been reported to be about 1.75 kGy (Urbain 1986; Grant and Patterson 1991), and 1.50 kGy (Urbain 1986), respectively.

The lipid oxidation process can be slowed down by the addition of antioxidants. Successful applications of natural antioxidants such as rosemary were reported in meat products such as turkey sausages (Barbut and others 1985) and restructured chicken nuggets (Lai and others 1991). Babut and others (1985) reported that the addition of rosemary oleoresin (20 ppm, based on the meat content) to turkey sausages produced a considerable reduction on TBARS values over a 15 days storage period at 4°C. Lai and others (1991) found a significant ($P < 0.01$) linear reduction in TBARS values at each test day in restructured chicken nuggets stored at 4°C as the concentration of oleoresin rosemary was increased from 0.0 to 0.1% of the total meat. On the contrary, Stoick and others (1991) observed no antioxidant activity in restructured beef steaks treated with oleoresin rosemary alone or in combination with sodium trypolyphosphate during refrigerated storage. Liu and others (1992) reported that the combination of oleoresin rosemary and sodium trypolyphosphate did not slow down lipid oxidation in restructured pork steaks stored at 4°C.

It is important to recognize that a variety of factors other than irradiation may affect the rate of lipid oxidation in meats prior and after the irradiation treatment. Some of these factors include the composition and freshness of the raw materials, cutting, chopping, flaking, emulsifying, cooking, and the addition of non-meat ingredients such as salt, spices, nitrite, and antioxidants (Kanner 1994). Intact muscles are less prone to lipid oxidation than mince or comminuted meat (Reineccius 1979). The addition of nitrite decreased lipid peroxidation in cured meat (Love and Pearson 1971). The addition of salt, nitrite, sodium ascorbate, and liquid smoke resulted in a more acceptable odor and color of ground beef and pork after irradiation and subsequent storage for 50 days (Erdman and Watts 1957). Ascorbic acid has been reported to improve both color and odor of irradiated cured meats (Erdman and Watts 1957).

Therefore, the purpose of this study was to determine if irradiation would significantly affect the lipid oxidation process, color, odor, and flavor of vacuum packaged turkey roll in the presence of rosemary extractives during storage at 2-4°C.

Materials and Methods

Preparation of turkey roll

Fresh, skinless, boneless turkey breasts were purchased from a local supermarket. The turkey breasts were trimmed free of most visible fat and connective tissue the day before manufacturing. Muscles were ground through a three-hole kidney plate (Brio grinder, Model 7552) and divided into six 10.57 kg batches. Ten percent of the meat from each batch was re-ground through a 0.47 cm plate to help the product bind together. The following treatments were randomly assigned to each batch of meat:

- No antioxidant (0 ppm), Not irradiated (0.0 kGy)
- No antioxidant (0 ppm), Irradiated (2.0 kGy)
- No antioxidant (0 ppm), Irradiated (3.2 kGy)
- Antioxidant (700 ppm), Not irradiated (0.0 kGy)
- Antioxidant (700 ppm), Irradiated (2.0 kGy)
- Antioxidant (700 ppm), Irradiated (3.2 kGy)

A list of the ingredients that were used is shown in Table 2.1. Each batch was mixed in a paddle mixer (Higashimoto Kikai Vacuum Mixer, Model 20) with all of the phosphate and half of the water for 30 seconds.

Table 2.1. Turkey roll formulation.

Ingredients	Percent (%)	Weight (g)
Coarse meat	69.93	9522.44
Fine meat	7.77	1058.05
Water	14.99	2040.82
Dextrose	2.00	272.11
Potassium lactate (60%)	3.00	408.16
Salt	1.75	238.35
Phosphate containing blend[a]	0.35	47.67
White pepper	0.12	17.00
Celery	0.02	2.72
Rosemary extractives[b]	0.07	9.53
Total	100.00	13616.85

[a] Contains sodium polyphosphates, glassy (sodium hexametaphosphate), and sodium bicarbonate
[b] Herbalox® seasoning (HT-W 41-19-13, Kalsec, Kalamazoo, MI) contains 23-33 % rosemary extractives.

Then, the remaining non-meat ingredients and the other half of the water were added and mixed for another two minutes.

The product was placed in a plastic tub and subsequently transferred into a tumbler (Inject Star System, Viena, Austria) where it was tumbled continuously for one and a half hours. After tumbling, the product was placed into a plastic tub and held overnight in a cooler at 2-4°C. The next morning, the product was stuffed into 10 mm water-impermeable casings (Devro Teepak, Westchester, IL) using a vacuum stuffer (Risco, Model RS 4003-165, Stoughton, MA). The product was steam cooked in a Maurer thermal processing oven (Model D-7752, Germany) using the thermal processing schedule in Table 2.2.

After thermal processing, the turkey rolls were chilled in a cooler at –1°C. Four days after thermal processing, the product was sliced into 20 mm thick slices using a Hobart slicing machine (Model 1712). The slices were stacked in groups of four slices, placed into Cryovac bags (B2550, size 16.25 mm X 20.0 mm) and

Table 2.2. Thermal processing unit schedule used for turkey roll.

Program (step)	Time (minutes)	Temperature (°C)	Moisture (%)	Core Temperatur (°C)
Steam Cook	30	60.0	---	---
Steam Cook	30	71.0	---	---
Steam Cook	---	82.2	---	71.1
Shower (Cold)	15	---	---	---

vacuum packaged using a Multivar Chamber Packaging Machine (Model AG 800, Seep Haggeumuller KG, Germany). The packages were then shrunk using hot water, dried, labeled, placed into boxes and stored in a cooler at –1°C for further data collection.

Irradiation

Sliced, vacuum packaged turkey roll samples were held for four days in a cooler at -1°C prior to the irradiation treatment. The product was irradiated at the Iowa State University Linear Accelerator Facility using a Circe IIIR Electron Beam (EB) irradiator (Thomson-CSF Linac, St. Aubin, France). Single-sided irradiation treatments were carried out at doses of 2.0 kGy or 3.2 kGy. Alanine pellets were placed at the bottom and top of two packages of sliced turkey roll to monitor the absorbed dose applied to the product. After the irradiation treatment, the product was stored in a cooler at -1°C.

Sensory evaluation I

Sensory evaluations were performed on day 28 (replication 1 and 2) and day 25 (replication 3) after the products were treated with irradiation. The sensory evaluations were carried out on Monday, Wednesday, and Friday (of the same week) for replication 1, 2, and 3, respectively. The sensory attributes that were evaluated consisted of off-odor intensity (no off-odor/intense off-odor), off-flavor intensity (no off-flavor/intense off-flavor), overall flavor intensity (bland flavor/full flavor), and color intensity (pale color/pink color).

A sensory panel of 16 people (only 12 panelists were used for this sensory evaluation) was trained by exposing them to both extremes for any parameter being evaluated. Sliced, vacuum packaged turkey roll manufactured using the formula previously mentioned without rosemary extractives (no antioxidant, not irradiated) was used as reference sample with no off-odor, no off-flavor, and full flavor during training. The same product (a second set of samples) was irradiated up to 10 kGy and used as a reference sample with intense off-odor and off-flavor. A second batch of turkey roll was produced to be used as a reference sample with bland flavor using the formula in Table 2.3.

The reference sample for pink color used was smoked, cured, sliced, and vacuum packaged turkey roll manufactured using the formula in Table 2.1 (without rosemary) in addition to 156 ppm of sodium nitrite and 547 ppm of sodium erythorbate. A piece of vacuum packaged white cheese was used as a reference sample for pale color during the training sessions. The panelists attended three training sessions the week before the

Table 2.3. Bland turkey roll formulation.

Ingredients	Percent (%)	Weight (g)
Coarse meat	71.78	9795.91
Fine meat	7.98	1088.44
Water	14.95	2040.82
Dextrose	1.00	136.05
Potassium lactate (60%)	3.00	408.6
Salt	0.87	119.17
Phosphate containing blend[a]	0.35	47.67
White pepper	0.06	8.50
Celery	0.01	1.36
Total	100.00	13646.52

[a] Contains sodium polyphosphates, glassy (sodium hexametaphosphate), and sodium bicarbonate

evaluations were conducted. During these training sessions the panelists evaluated the products under the same conditions they were to evaluate the products during the sensory evaluation I.

The samples for the off-odor, off-flavor, and overall flavor intensity evaluations were cut into 2 x 1 cm pieces, placed into petri dishes (identified with a random three-digit code number) and tempered at room temperature (25°C) for 30 minutes prior to evaluation. These attributes were evaluated under red lights. Then, the color intensity of the turkey roll was evaluated under fluorescent lights using another set of vacuum packaged samples identified with a three-digit code number.

Six samples were presented to each panelist during a sensory evaluation session. A double grouping design (Cochran and Cox 1992) was used to collect the data for the off-odor, off-flavor, and overall flavor intensity sensory evaluations to study the effect of order of presentation of the meat samples on the panelists' scores. Individual sets of three-digit code numbers and different random orders of presentation were used for each panelist. The panelists evaluated the samples using a 150 mm, unstructured scale with anchored descriptors. The off-odor, off-flavor, and overall flavor intensities were evaluated using one evaluation form (Figure 2.1) per sample. The color intensity was evaluated using one form for all six samples (Figure 2.2).

Sensory evaluation II

Sensory evaluations were performed on day 21 (replications 1 and 2) and day 18 (replication 3) after the products were treated with irradiation. The sensory evaluations were carried out on Monday, Wednesday,

Turkey Roll Sensory Evaluation Form I

Panelist # _____
Sample # _____
Date _____

Step one: Evaluate the odor intensity of the turkey roll sample provided by sniffing the sample. Open the container briefly and sniff the content. Use several short shallow sniffs. Close the container and mark your evaluation with a vertical line on the following scale.

Off-odor: Rate the intensity of any odor **not normally associated** with turkey roll.

No off-odor — Intense off-odor

Step two: Now taste the sample. Chew the sample as you would normally and swallow or discard. If you choose to discard the sample you must do so for all samples. After tasting, mark your evaluation with a vertical line on the appropriate scale.

Off-flavor: Rate the intensity of any displeasing flavor **not normally associated** with turkey roll.

No off-flavor — Intense off-flavor

Overall Flavor Intensity: Rate the intensity of the flavor **normally associated** with turkey roll.

Bland flavor — Full flavor

Figure 2.1. Sensory evaluation score sheet for off-odor, off-flavor, and overall flavor.

Turkey Roll Sensory Evaluation Form II

Panelist # _____
Date _____

Evaluate the color intensity of the turkey roll sample provided. Mark your evaluation with a vertical line on the appropriate scale.

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Figure 2.2. Sensory evaluation score sheet for color.

and Friday (of the same week) for replication 1, 2, and 3, respectively. The same 16 panelists trained for the sensory evaluation I were used for sensory evaluation II without further training. In sensory evaluation II, the meat samples were presented warm and cold to the panelists. A total of four treatments, not irradiated (warm and cold) turkey roll and irradiated (3.2 kGy, warm and cold) turkey roll, were used for this sensory evaluation. The sensory attributes evaluated consisted of off-odor intensity (no off-odor/intense off-odor), off-flavor intensity (no off-flavor/intense off-flavor), and overall flavor intensity (bland flavor/full flavor) of the meat samples.

Four sets of meat samples were cut into 2 x 1 cm pieces. Two sets (cold samples) were placed into petri dishes (identified with a random three-digit code number) and tempered at room temperature (25°C) for 30 minutes prior to evaluation. The other two sets (hot samples) were placed into aluminum trays, heated to 62.8°C average core temperature in a conventional oven (Faberware Inc. Convection/Broil oven, Model T4850), placed into petri dishes (identified with a random three-digit code number) and presented to the panelist.

Four samples were presented to each panelist during a sensory evaluation. The double grouping design was also used during the sensory evaluation II to study the effect of order of presentation of the meat samples on the panelists' scores. Individual sets of three-digit code numbers and different random orders of presentation were used for each panelist. These attributes were evaluated under red lights using a 150 mm, unstructured scale with anchored descriptors (Figure 2.1).

Chemical and physical analyses

Lipid oxidation was monitored using the thiobarbituric acid reactive substances (TBARS) method reported by Tarladgis and others (1960). Color changes were evaluated using a Hunterlab Labscan instrument (Hunterlab Labscan, Model LS 5100). The CIE L* (lightness), CIE a* (redness/greenness), and the CIE b* (yellowness/blueness) were obtained using a 25 mm port size with a 10° observer and an A illuminant. The instrument was standardized prior to each use by covering the white and black tiles with a piece of the same packaging material used to package the product. Three measurements were taken at different locations of one package of vacuum packaged turkey roll during each day of evaluation. Samples were evaluated for both oxidation (TBARS) and color changes (CIE L*, a*, and b*) on day 1, 3, 5, 10, 15, 30, 46, and 60.

Statistical analysis

The experiment design was a 2x3 factorial treatment design. TBARS values and CIE L*, a*, and b* color values were analyzed using a split plot design with respect to time. The sensory data was evaluated using the standard errors suggested by Cochran and Cox (1992) to consider the number of panelists used in the double grouping design. All data sets were analyzed using a General Linear Model with the Statistical Analysis System (SAS Institute, Inc. 2000). Least square means and an alpha level of $P < 0.05$ were used to determine significance for all data. The experiment was replicated three times.

Results and Discussion

The effects of rosemary extractives and irradiation treatments on TBARS values of turkey roll are summarized in Table 2.4. The addition of rosemary extractives to the turkey roll significantly ($P < 0.05$) reduced the production of TBARS values. Rosemary significantly ($P < 0.05$) prevented the formation of lipid oxidation compounds during a 60 days storage period. Barbut and others (1985) observed similar results when rosemary (20 ppm based on the meat content) was added to turkey sausages stored for 15 days at 4°C. Lai and others (1991) reported a significant ($P < 0.01$) linear reduction on TBARS values of restructured chicken nuggets at each test day as the concentration of rosemary oleoresin was increased from 0.0 to 0.1% of the total weight of the meat. Statistical analysis of the TBARS values indicated that the irradiation treatments had no significant effects on lipid oxidation of vacuum packaged turkey roll (Table 2.4). Ahn and others (1998) observed similar results in irradiated (2.5 kGy) and then cooked turkey breast patties stored for 7 days at 4°C. Shults and others (1977b) observed lower TBARS values in irradiated (30-60 kGy) canned pork rolls when compared with the control.

CIE L*, a*, and b* data are displayed in Table 2.4 according to treatment. The CIE L* values of the turkey roll were not affected by either the addition of rosemary extractives or the irradiation doses used in this study. These results agree with those reported by Nanke and others (1998) where irradiation treatments up to 10.5 kGy had no effect on the CIE L* values of fresh turkey meat. The CIE a* values of irradiated turkey roll significantly increased ($P < 0.05$) in a dose dependent manner. The intensity of the pink color produced during the irradiation treatment did not change over storage time based on CIE a* values. Nanke and others (1998) observed similar results in irradiated (4.5 kGy), fresh turkey breasts. The CIE b* values significantly ($P< 0.05$)

Table 2. 4. Means of main effects for lipid oxidation and color analyses of turkey roll[z].

MAIN EFFECTS		OXIDATION TBARS	COLOR L*	COLOR a*	COLOR b*
ANTIOXIDANT	0 ppm	1.34[b]	75.78	10.79	14.48[a]
	700 ppm	0.84[a]	75.71	10.72	14.95[b]
	SEM	0.04	0.09	0.04	0.05
IRRADIATION	0.0 kGy	1.19	75.79	8.83[a]	16.03[c]
	2.0 kGy	1.09	75.54	11.26[b]	14.33[b]
	3.2 kGy	0.98	75.90	12.17[c]	13.78[a]
	SEM	0.05	0.11	0.05	0.06
ANTIOXIDANT*IRRADIATION	0 ppm + 0.0 kGy	1.50	76.00	8.72	15.82
	0 ppm + 2.0 kGy	1.35	75.30	11.51	14.13
	0 ppm + 3.2 kGy	1.15	76.03	12.13	13.48
	700 ppm + 0.0 kGy	0.87	75.58	8.94	16.23
	700 ppm + 2.0 kGy	0.83	75.77	11.02	14.53
	700 ppm + 3.2 kGy	0.82	75.77	12.22	14.08
	SEM	0.07	0.16	0.07	0.08

[z] Values within columns, for any given main effect or interaction, with differeng superscripts are significantly different at $P < 0.05$.
Means of 72, 48 and 24 numbers for antioxidant, irradiation and oxidant*irradiation respectively (3 replications, 2 antioxidant levels, 3 irradiation deses and 8 storage days).

Table 2.5. Turkey roll TBARS values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C							
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	3	5	10	15	30	46	60
0 ppm	0 kGy	1.37	1.70	1.36	1.77	1.46	2.01	1.33	1.04
	2.0 kGy	1.47	1.94	1.38	1.37	1.17	1.41	1.12	0.97
	3.2 kGy	1.26	1.40	1.17	1.09	1.01	1.33	1.02	0.95
700 ppm	0 kGy	0.78	0.93	0.85	0.92	0.89	0.95	0.83	0.84
	2.0 kGy	0.84	0.85	0.84	0.81	0.84	0.80	0.86	0.84
	3.2 kGy	0.96	0.82	0.77	0.82	0.80	0.78	0.75	0.84
	SEM	0.16	0.23	0.11	0.1	0.012	0.22	0.06	0.07

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

Table 2.6. Turkey roll CIE L* values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C							
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	3	5	10	15	30	46	60
0 ppm	0 kGy	76.02	76.32	76.29	76.26	75.81	75.71	75.45	76.20
	2.0 kGy	75.10	76.77	74.92	75.67	75.24	74.77	74.75	75.19
	3.2 kGy	76.60	75.93	75.89	76.10	76.30	75.60	75.76	76.02
700 ppm	0 kGy	74.92	76.24	75.41	75.88	75.74	75.74	75.21	75.49
	2.0 kGy	76.22	76.00	76.14	75.64	75.80	75.24	76.22	74.94
	3.2 kGy	76.02	76.19	75.78	75.88	75.23	76.05	75.49	75.54
SEM		0.52	0.46	0.51	0.32	0.37	0.40	0.26	0.39

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

Table 2.7. Turkey roll CIE a* values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C							
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	3	5	10	15	30	46	60
0 ppm	0 kGy	8.86	8.87	8.64	8.69	8.73	8.69	8.72	8.57
	2.0 kGy	10.77	10.98	11.85	12.17	11.50	11.52	11.92	11.33
	3.2 kGy	10.80	11.71	11.87	12.14	12.03	12.95	12.52	13.03
700 ppm	0 kGy	9.19	8.84	8.93	8.94	8.80	8.99	8.92	8.88
	2.0 kGy	10.64	11.16	11.10	11.36	11.37	10.94	10.76	10.83
	3.2 kGy	11.37	11.44	12.00	12.41	12.83	12.42	12.51	12.76
SEM		0.21	0.17	0.17	0.26	0.18	0.25	0.08	0.14

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

Table 2.8. Turkey roll CIE b* values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C							
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	3	5	10	15	30	46	60
0 ppm	0 kGy	15.64	15.87	15.71	15.61	15.63	15.83	16.10	16.20
	2.0 kGy	13.66	13.95	13.76	14.10	14.17	14.46	14.44	14.50
	3.2 kGy	13.38	13.43	13.34	13.34	13.27	13.95	13.57	13.61
700 ppm	0 kGy	16.14	15.80	16.20	16.27	16.14	16.32	16.44	16.53
	2.0 kGy	14.12	14.09	13.96	14.28	14.50	15.04	15.11	15.18
	3.2 kGy	14.32	13.81	13.83	13.68	14.15	14.27	14.36	14.19
SEM		0.16	0.16	0.24	0.18	0.09	0.17	0.24	0.20

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

increased by the addition of rosemary extractives, but the differences were so small that they are not of practical importance. The CIE b* values of the turkey roll significantly ($P < 0.05$) decreased as the irradiation doses were increased from 0.0-3.2 kGy. This means that as the irradiation dose was increased the turkey roll became less yellow. The opposite was reported by Nanke and others (1998) where an increase in b* values of turkey breast was observed as the irradiation dose was increased from 0.0-7.5 kGy.

No order of presentation of meat samples effect was observed during the sensory evaluation of the cold turkey roll (2.9). The addition of rosemary extractives showed no effect on the sensory attributes evaluated (Table 2.10). On the other hand, irradiation significantly ($P < 0.05$) increased the pinkness scores for turkey roll in a dose dependent manner (Table 2.11). This means that the panelists detected significant ($P < 0.05$) differences in the color intensity not only between the irradiated and non-irradiated turkey roll, but also between the turkey roll irradiated with a dose of 2.0 kGy and 3.2 kGy as well. Similar results were observed by Nanke and others (1998) in fresh, vacuum packed turkey meat irradiated at doses ranging from 0.0 kGy to 4.5 kGy.

Irradiation also increased the off-odor intensity of the cold turkey roll (Table 2.11). The off-odor intensity was ranked significantly ($P < 0.05$) higher as the irradiation dose applied to the turkey roll was increased from 0.0-3.2 kGy. Heath and others (1990) reported that a sensory panel was able to detect significant differences in the odor of irradiated (2.0 kGy), cooked (85°C), cubed and heated (85°C) chicken thighs using a triangle test. However, they also found that irradiation doses up to 3.0 kGy did not affect the odor of chicken breast.

Panelists detected a significant increase ($P < 0.05$) in the off-flavor intensity of the turkey roll only when a dose of 3.2 kGy of irradiation was applied to the product (Table 2.11). However, no significant differences ($P > 0.05$) in off-flavor were detected by the sensory panel when an irradiation dose of 2.0 kGy was applied to the turkey rolls. A significant ($P < 0.05$) increase in off-flavor was detected in irradiated frankfurters when doses of 8.0 kGy and 32 kGy were applied to the product (Terrell and others 1981).

Irradiation did not affect the overall flavor intensity of the cold turkey roll (Table 2.11). This means that irradiation neither reduced, nor enhanced the flavors resulting from the addition of non-meat ingredients to the turkey roll in this study. Terrell and others (1982) reported that 32 kGy irradiation dose will affect the sensory perceptions of irradiated frankfurters regardless of the spice blend added to the product.

Table 2.9. Means of order of presentation of meat samples effect for turkey roll sensory evaluation I[z].

ORDER	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY	OVERALL FLAVOR INTENSITY
1	66.5	62.6	88.3
2	46.4	52.2	84.7
3	44.0	39.7	77.9
4	50.9	48.5	73.9
5	42.3	38.8	76.1
6	40.3	43.4	80.4
SEM	4.5	5.8	4.3

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$

Means are score out of 150 maximum.

Means of 36 numbers (3 replications and 12 panelists).

Table 2.10. Means of antioxidant effects for turkey roll sensory analysis I[z].

ANTIOXIDANT	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY
0 ppm	49.3	49.6
700 ppm	47.5	45.5
SEM	2.6	3.3
ANTIOXIDANT	OVERALL FLAVOR INTENSITY	COLOR INTENSITY
0 ppm	77.1	75.1
700 ppm	83.3	72.7
SEM	2.5	2.0

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.

Means are score out of 150 maximum.

Means of 108 numbers (3 replications, 12 panelists and 3 measurements per panelist).

Table 2.11. Means of irradiation dose effects for turkey roll sensory analysis I[z].

IRRADIATION DOSE (kGy)	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY
0.0	30.1^{a}	35.9^{a}
2.0	50.9^{b}	45.4^{a}
3.2	64.2^{c}	61.4^{b}
SEM	3.2	4.1
IRRADIATION DOSE (kGy)	OVERALL FLAVOR INTENSITY	COLOR INTENSITY
0.0	75.5	28.0^{a}
2.0	83.0	80.6^{b}
3.2	82.2	113.1^{c}
SEM	3.1	2.5

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.

Means are score out of 150 maximum.

Means of 72 numbers (3 replications, 12 panelists and 2 measurements per panelists).

There was no order of presentation effect observed when the turkey roll was evaluated warm (heated up to 62.8°C) and cold during a second sensory evaluation (Table 2.12). Heat had no effect on the sensory attributes evaluated during this sensory evaluation (Table 2.13). The panelists detected significant differences ($P < 0.05$) in off-odor and off- flavor intensities between irradiated (3.2 kGy) and non-irradiated turkey roll regardless of whether the samples were warm or cold (Table 2.14).

Conclusions

The rosemary extractives used in this study showed to have the potential to reduce the formation of lipid oxidation compounds without affecting the sensory characteristics of turkey roll. Ionizing irradiation treatments produced a pink color in vacuum packaged turkey roll that remained for 60 days. The sensory panel determined that an irradiation dose of 3.2 kGy produced an increase in the off-odor and off-flavor intensities of the turkey roll that was present regardless of whether the products were sampled warm or cold. However, the panelists did not detect an increase in the off-flavor intensity when an irradiation dose of 2.0 kGy was applied to the turkey roll and evaluated cold.

Table 2.12. Means of order of presentation of meat samples for turkey roll sensory analysis II[z].

ORDER	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY	OVERALL FLAVOR INTENSITY
1	61.7	54.4	91.0
2	58.2	62.5	84.7
3	56.2	51.1	71.6
4	67.1	60.3	85.2
SEM	3.7	5.5	5.5

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.

Means are score out of 150 maximum.

Means of 48 numbers (3 replications and 16 panelists).

Table 2.13. Means of heat effects for turkey roll sensory analysis II[z].

HEAT	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY	OVERALL FLAVOR INTENSITY
N	62.3	60.9	81.4
Y	59.3	53.3	84.8
SEM	2.6	3.9	3.9

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.

Means are score out of 150 maximum.

Means of 96 numbers (3 replications, 16 panelists and 2 measurements per panelist).

Table 2.14. Means of irradiation dose effects for turkey roll sensory analysis II[z].

IRRADIATION DOSE (kGy)	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY	OVERALL FLAVOR INTENSITY
0.0	46.3[a]	42.3[a]	84.4
3.2	75.3[b]	71.8[b]	81.8
SEM	2.6	3.9	3.9

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.

Means are score out of 150 maximum.

Means of 96 numbers (3 replications, 16 panelists and 2 measurements per panelist).

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CHAPTER 3. THE EFFECTS OF ROSEMARY EXTRACTIVES AND ELECTRON BEAM IRRADIATION ON LIPID OXIDATION, COLOR, ODOR, AND FLAVOR OF VACUUM PACKAGED HAM

A paper to be submitted to the Journal of Food Science

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Abstract

The effect of irradiation treatments (0.0-3.2 kGy), in combination with rosemary extractives, on lipid oxidation (TBARS), color (CIE L*, a*, and b*), odor, and flavor of vacuum packaged hams stored at 2-4°C for 60 days were studied. Sensory evaluations were performed to determine differences in color, off-odor, off-flavor, and overall flavor intensities of cold and reheated hams. Rosemary significantly ($P < 0.05$) increased the CIE L* values of the hams. Sensory panelists detected higher off-odor and off-flavor intensities in the irradiated hams. Heat decreased the off-odor intensity of the hams. An aroma scan analysis showed a significant ($P < 0.05$) reduction of volatile compounds present in the irradiated (3.2 kGy) hams.

Introduction

Pathogens such as *Listeria monocytogenes* can be eliminated from ready-to-eat meat products using a proper thermal process (Carlier and others 1996). However, these pathogens can be reintroduced to the finished products during the slicing and packaging processes (Wang and Muriana 1994). Low storage temperature does not prevent the growth of pathogens such as *Listeria monocytogenes* once recontamination occurs (Beumer and others 1996). Irradiation treatments (1.5-10 kGy) can be used to reduce and/or eliminate pathogenic, as well as non-pathogenic bacteria that may be present in meat products (Thayer and others 1996; Olson 1995). However, irradiation produces changes in color, flavor, and odor that may reduce the acceptability of irradiated meats (Shay and others 1988). A combination of treatments, such as vacuum packaging and low temperature storage, can be used to minimize these undesirable changes produced by ionizing irradiation (Rosenthal 1992; Olson 1995).

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The production of free radicals, as the result of the reaction of ionizing irradiation and water, leads to changes in color, flavor, and odor in the product being treated (Proctor and others 1952). These radicals can yield lipid radicals via free radical reactions and/or hydroperoxides in the presence of oxygen (Thakur and Singh 1994). These peroxides subsequently deteriorate into a variety of compounds such as alkenes, alkanes, aldehydes, and alcohols during further reactions (Patterson and Stevenson 1995). The extent of the changes produced by ionizing irradiation may vary depending on the food being treated, the dose being applied, and the processing techniques being used (Proctor and others 1952).

Gamma irradiation (32 kGy) was found to decrease the cured color intensity in ham (Kamarie and others 1981). Shults and others (1977a) reported that as the irradiation dose increased from 2.5 to 4.5 megarad (25-45 kGy) the discoloration rating increased in corned beef briskets. However, a medium dose (1.8-2.0 kGy) of ionizing irradiation did not affect the color of vacuum packaged ham stored at 2-4°C (Fu and others 1995). Modified atmosphere packaging, such as carbon dioxide (CO_2), resulted in the production of more desirable color in irradiated (1.75 kGy) pork chops (Grant and Patterson 1991). Fresh meat treated with irradiation under modified atmosphere packaging showed conversion of brown metmyoglobin to the desirable pink color of oxymyoglobin (Groninger and others 1956).

Changes in the sensory perceptions of irradiated (5.0 kGy) hams were found to be unacceptable ($P < 0.1$) by a group of families in a consumer test in Denmark. The participants detected differences ($P < 0.1$) in flavor between the irradiated and not irradiated hams (Hansen 1966). Irradiated (32 kGy) frankfurters were found to have a strong off-flavor and a significant ($P < 0.05$) reduction in their overall palatability when compared with the control (Terrell and others 1981). A non-characteristic odor was detected in sliced ham and bologna irradiated at doses between 2×10^5 and 2×10^6 rep (2.0-20 kGy) and packaged in an aerobic environment. The odor of the ham did not change upon storage, however, the bologna developed a rancid odor after 7 days of storage (Erdman and Watts 1957). Grant and Patterson (1991) reported that the odor of irradiated pork changed from a "burnt" odor to a "dairy" odor during storage due to proliferation of lactic acid bacteria in a modified atmosphere package. Lynch and others (1991) reported that turkey fillets treated with irradiation (2.5 kGy) developed an objectionable odor that increased after 21 days of storage.

Significant changes in meat flavor and aroma have been reported even at irradiation doses as low as 2.0 kGy (Shay and others 1988). Off-odors produced during the irradiation treatment of fresh meats might be associated with the production of volatile sulfur compounds from glutathione and proteins containing sulfhydryl groups (Batzer and Doty 1955). Ahn and others (2000) hypothesized that the off-odor produced in irradiated meats are the result of the radiolitic breakdown of sulfur containing amino acids. Dimethyltrisulphide was reported to be the main sulfur containing compound present in raw chicken meat treated with a medium dose (2.5 kGy) of ionizing irradiation (Patterson and Stevenson 1995).

Irradiation treatments may alter the lipid oxidation process of processed meat. Terrell and others (1981) observed an increase in the TBARS values of irradiated frankfurters when the irradiation doses were increased from 0.0 to 3.2 megarad (0.0-32 kGy). Zhao and others (1996) reported that the TBARS values of irradiated (1.0 kGy), vacuum packaged pork chops were significantly higher ($P < 0.05$) than the control. Mattison and others (1986) and Lambert and others (1992) reported that irradiation (1.0 kGy) did not affect the TBARS values of vacuum packaged pork loins. Ahn and others (1998) reported that the TBARS values of irradiated (2.5 kGy) and then cooked turkey breast patties were not affected by the irradiation treatment. Shults and others (1977a) found similar results in irradiated (25-45 kGy) corned beef briskets.

The production of volatile compounds and the TBARS values of cooked turkey meat have shown to be correlated. A higher concentration of aldehydes such as propanal, pentanal, hexanal have been reported in irradiated (2.5 kGy) and then cooked turkey meat stored for 7 days at 4°C (Ahn and others 1998). Also, an increase in the amount of carbonyl compounds was observed in pre-cooked, irradiated (18.6-27.9 kGy), canned pork chops and veal shoulder clods stored at 2°C. The same study revealed that the cooking process increased the concentration of carbonyls and hydrogen sulfides, followed by a further increase as a result of the irradiation treatment (Pearson and others 1959).

Combination treatments help to prevent or reduce undesirable changes in the sensory perceptions of irradiated meat. Investigators have agreed that the exclusion of oxygen during the irradiation process decreases color deterioration in fresh meat (Urbain 1986; Shay and others 1988; Lambert and others 1992; Lefebvre and others 1994). The application of irradiation treatments at low temperatures (0 to -30 ± 10°C) reduced the levels of discoloration of irradiated corned beef briskets at doses of 25 kGy and 35 kGy (Shults and others 1977a).

Lai and others (1991) found a significant ($P < 0.01$) linear reduction in TBARS values at each test day in restructured chicken nuggets stored at 4°C as the concentration of oleoresin rosemary was increased from 0.0 to 0.1 % of the total weight of the meat. The addition of nitrite decreased lipid peroxidation in cured meat (Love and Pearson 1971). The addition of salt, nitrite, sodium ascorbate, and liquid smoke resulted in a more acceptable odor and color of ground beef and pork after irradiation and subsequent storage for 50 days. Ascorbic acid has been reported to improve both color and odor of irradiated cured meats (Erdman and Watts 1957). The addition of ascorbate in combination with nitrite may provide some protection against undesirable odor and color changes induced by irradiation; however, ascorbate may induce lipid oxidation over long storage periods (Erdman and Watts 1957).

Therefore, the purpose of this study was to determine if irradiation would significantly affect the lipid oxidation process, color, odor, and flavor of vacuum packaged ham in the presence of rosemary extractives during storage at 2-4°C.

Materials and Methods

Preparation of ham

Fresh, skinless, bone-in hams were purchased from a local supermarket. The hams were de-boned and the muscles were trimmed free of fat and connective tissue using a Townsend membrane skinner (Model 7600, Townsend Engineering Inc., Des Moines, IA). The muscles were vacuum packaged and stored in a cooler at 2-4°C for no longer than five days until further processed. Muscles were ground through a three-hole kidney plate (Brio grinder, Model 7552) and divided into six 9.54 kg batches. Ten percent of the meat from each batch was re-ground through a 0.47 cm plate to help the product bind together. The following treatments were randomly assigned to each batch of meat:

- No antioxidant (0 ppm), Not irradiated (0.0 kGy)
- No antioxidant (0 ppm), Irradiated (2.0 kGy)
- No antioxidant (0 ppm), Irradiated (3.2 kGy)
- Antioxidant (700 ppm), Not irradiated (0.0 kGy)
- Antioxidant (700 ppm), Irradiated (2.0 kGy)
- Antioxidant (700 ppm), Irradiated (3.2 kGy)

A list of the ingredients that were used is shown in Table 3.1. Each batch was mixed in a paddle mixer (Higashimoto Kikai Vacuum Mixer, Model 20) with all of the phosphate and half of the water for 30 seconds. Then, the remaining non-meat ingredients and the other half of the water were added and mixed for another two minutes. The product was placed in a plastic tub and subsequently transferred into a tumbler (Inject Star System, Viena, Austria) where it was tumbled continuously for one and a half hours. After tumbling, the product was placed into a plastic tub and held overnight in a cooler at 2-4°C. The next morning, the product was stuffed into 10 mm casings (Devro Teepak, Westchester, IL) using a vacuum stuffer (Risco, Model RS 4003-165, Stoughton, MA). The product was smoked and cooked in a Maurer thermal processing oven (Model D-7752, Germany) using the thermal processing schedule in Table 3.2.

After thermal processing, the hams were chilled overnight in a cooler at –1°C. The next morning, the product was sliced into 20 mm thick slices using a Hobart slicing machine (Model 1712). The slices were stacked in groups of four slices, placed into Cryovac bags (B2550, size 16.25 mm X 20.0 mm) and vacuum packaged using

Table 3.1 Ham formulation.

Ingredients	**Percent (%)**	**Weight (g)**
Coarse meat	63.12	8588.33
Fine meat	7.01	954.25
Water	25.00	3401.36
Salt	2.58	351.02
Sugar	1.65	224.49
Phosphate containing blend[a]	0.35	47.62
Curing salt (6.25 % sodium nitrite	0.17	23.80
Sodium erythorbate	0.03	5.21
Rosemary extractives[b]	0.07	9.52
Total	100.00	13605.60

[a] Contains sodium polyphosphates, glassy (sodium hexametaphosphate), and sodium bicarbonate
[b] Herbalox® Seasoning (HT-W 41-19-13, Kalsec, Kalamazoo, MI) contains 23-33 % rosemary extractives.

Table 3.2 Thermal processing oven schedule used for ham.

Program (step)	**Time (minutes)**	**Temperature (°C)**	**Moisture (%)**	**Core Temperature (°C)**
Reddening	45	60.0	---	---
Drying	30	73.8	---	---
Hot Smoke Fast	30	73.8	---	---
Cold Smoke Slow	15	73.8	45	---
Hot Smoke Fast	30	76.6	45	---
Hot Air Finishing	---	79.4	60	60
Hot air Finishing	---	82.2	70	70
Shower	15	---	---	---

a Multivar Chamber Packaging Machine (Model AG 800, Seep Haggeumuller KG, Germany). The packages were shrunk using hot water, dried, labeled, placed into boxes and stored in a cooler at –1°C for further data collection.

Irradiation

Sliced, vacuum packaged ham samples were held for two days in a cooler at –1°C prior to the irradiation treatment. The product was irradiated at the Iowa State University Linear Accelerator Facility using a Circe IIIR Electron Beam (EB) irradiator (Thomson-CSF Linac, St. Aubin, France). Single-sided irradiation treatments were carried out at doses of 2.0 kGy or 3.2 kGy. Alanine pellets were placed at the bottom and top of two packages of sliced ham to monitor the absorbed dose applied to the product. After the irradiation treatment, the product was stored in a cooler at –1°C for further data collection.

Sensory evaluation I

Sensory evaluations were performed on day 18 (replication), day 17 (replication 2) and day 15 (replication 3) after the products were treated with irradiation. The sensory evaluations were carried out on Monday, Wednesday, and Friday (of the same week) for replication 1, 2, and 3, respectively. The sensory attributes that were evaluated consisted of off-odor intensity (no off-odor/intense off-odor), off-flavor intensity (no off-flavor/intense off-flavor), overall flavor intensity (bland flavor/full flavor), and color intensity (pale color/pink color).

A sensory panel of 12 people was trained by exposing them to both extremes for any parameter being evaluated. Sliced, vacuum packaged hams manufactured using the formula in Table 3.1 without rosemary extractives (no antioxidant, not irradiated) were used as reference sample with no off-odor, no off-flavor, and full flavor during training. The same product (a second set of samples) was irradiated up to 10 kGy and used as a reference sample with intense off-odor and off-flavor. A batch of smoked and cooked pork was produced to be used as a reference sample with bland flavor and pale color using the formula in Table 3.3. The reference sample for pink color used was vacuum packaged dried beef. The panelists attended three training sessions the week before the sensory evaluations were conducted. During these training sessions the panelists evaluated the products under the same conditions they were to evaluate the products during the sensory evaluation I.

The samples for the off-odor, off-flavor, and overall flavor intensity evaluations were cut into 2 x 1 cm pieces, placed into petri dishes (identified with a random three-digit code number) and tempered at room

Table 3.3. Bland and pale pork formulation.

Ingredients	Percent (%)	Weight (kg)
Coarse Meat	65.60	4462.53
Fine Meat	7.29	495.84
Water	25.00	1700.68
Salt	1.76	119.86
Phosphate containing blend[a]	0.35	23.81
Total	100.00	6802.69

[a] Contains sodium polyphosphates, glassy (sodium hexametaphosphate), and sodium bicarbonate

temperature (25°C) for 30 minutes prior to evaluation. These attributes were evaluated under red lights. Then, the color intensity of the hams were evaluated under fluorescent lights using another set of vacuum packaged samples identified with a three-digit code number.

Six samples were presented to each panelist during a sensory evaluation session. A double grouping design (Cochran and Cox 1992) was used to collect the data for the off-odor, off-flavor, and overall flavor intensity sensory evaluations to study the effect of order of presentation of the meat samples on the panelists' scores. Individual sets of three-digit code numbers and different random orders of presentation were used for each panelist. The panelists evaluated the samples using a 150 mm, unstructured scale with anchored descriptors. The off-odor, off-flavor and overall flavor intensities were evaluated using one evaluation form (Figure 3.1) per sample. The color intensity was evaluated using one form for all six samples (Figure 3.2).

Sensory evaluation II

Sensory evaluations were performed on day 25 (replications 1) day 24 (replication 2) and day 22 (replication 3) after the products were treated with irradiation. The sensory evaluations were carried out on Monday, Wednesday, and Friday (of the same week) for replication 1, 2, and 3, respectively. The same 12 panelists trained for the sensory evaluation I were used for sensory evaluation II without further training. In sensory evaluation II, the meat samples were presented warm and cold to the panelists. A total of four treatments, not irradiated (warm and cold) ham and irradiated (3.2 kGy, warm and cold) ham, were used for this sensory evaluation. The sensory attributes evaluated consisted of off-odor intensity (no off-odor/intense off-odor), off-flavor intensity (no off-flavor/intense off-flavor), and overall flavor intensity (bland flavor/full flavor) of the meat samples.

Four sets of meat samples were cut into 2 x 1 cm pieces. Two sets (cold samples) were placed into petri dishes (identified with a random three-digit code number) and tempered at room temperature (25°C) for 30

Ham Sensory Evaluation Form I

Panelist # _____
Sample # _____
Date _____

Step one: Evaluate the odor intensity of the ham sample provided by sniffing the sample. Open the container briefly and sniff the content. Use several short shallow sniffs. Close the container and mark your evaluation with a vertical line on the following scale.

Off-odor: Rate the intensity of any odor **not normally associated** with ham.

No off-odor — Intense off-odor

Step two: Now taste the sample. Chew the sample as you would normally and swallow or discard. If you choose to discard the sample you must do so for all samples. After tasting, mark your evaluation with a vertical line on the appropriate scale.

Off-flavor: Rate the intensity of any displeasing flavor **not normally associated** with ham.

No off-flavor — Intense off-flavor

Overall Flavor Intensity: Rate the intensity of the flavor **normally associated** with ham.

Bland flavor — Full flavor

Figure 3.1. Sensory evaluation score sheet for off-odor, off-flavor, and overall flavor.

Ham Sensory Evaluation Form II

Panelist # _____
Date _____

Evaluate the color intensity of the ham sample provided. Mark your evaluation with a vertical line on the appropriate scale.

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Color:

Sample # _____

Pale Pink

Figure 3.2. Sensory evaluation score sheet for color.

minutes prior to evaluation. The other two sets (hot samples) were placed into aluminum trays, heated to 62.8°C average core temperature in a conventional oven (Faberware Inc. Convection/Broil oven, Model T4850), placed into petri dishes (identified with a random three-digit code number) and presented to the panelist.

Four samples were presented to each panelist during a sensory evaluation. The double grouping design was also used during the sensory evaluation II to study the effect of order of presentation of the meat samples on the panelists' scores. Individual sets of three-digit code numbers and different random orders of presentation were used for each panelist. These attributes were evaluated under red lights using a 150 mm, unstructured scale with anchored descriptors (Figure 3.1).

Aroma Scan analysis

Aroma profiles of warm and cold ham samples were measured using an Aroma Scan A32S (Aroma Scan Inc., Hollis, NH). The aroma of the following six treatments combinations were evaluated:

- Not irradiated (0.0 kGy), cold (tempered at room temperature ≈ 25°C)
- Not irradiated (0.0 kGy), warm (heated to 62.8°C)
- Irradiated (2.0 kGy), cold (tempered at room temperature ≈ 25°C)
- Irradiated 2.0 kGy), warm (heated to 62.8°C)
- Irradiated (3.2 kGy), cold (tempered at room temperature ≈ 25°C)
- Irradiated (3.2 kGy), warm (heated to 62.8°C)

To prepare the warm samples, two slices of ham were cut into 2 x 1 cm pieces, placed into aluminum trays, and heated to 62.8°C average core temperature in a conventional oven. The ham samples were then placed into 500 ml Aroma Scan bags fitted with one-way valve, and the bags were sealed. To prepare the cold samples, tow slices of ham were cut into 2 x 1 cm pieces, placed into the 500 ml bags, and the bags were sealed. Then the cold samples were tempered at room temperature (25°C). Five bags per treatment were prepared for each replication and stored overnight (10 hours) at 4°C.

The six treatments and the three replications were analyzed the same day (day 30 for replication 1, day 26 for replication 2, and day 23 for replication 3). Air samples were ran at the beginning of the experiment to test the sensors' baseline accuracy. The sets of five bags were randomly pulled out (one at the time) from the refrigerated storage and kept in the dark for 30 minutes until they reached room temperature (≈ 23°C). The five

bags were then placed in the Aroma Scan incubator until analyzed. The total time of measurement was 330 seconds, which was divided into 30 seconds referencing (zeroing) with water vapor, 180 seconds of sampling, 30 seconds of washing with 2% isopropyl alcohol in water and 90 seconds of referencing. The data was collected during the 153 to 203 seconds time interval. The working conditions of the Aroma Scan were 4.5% reference relative humidity (RH), 10% RH in the air to fill the bags, and 70% RH in the final sample air. The temperature of the Aroma Scan incubator was set at 25°C and the sensors' temperature was set at 35°C.

The data obtained from the following four sensors with strong (S) and very strong (V) sensitivity to lipid oxidation compounds was used:

- Sensor # 17 (S - long chain alcohols, hydrocarbons, and ketones)
- Sensor # 22 (S - short chain alcohols and ketones)
  (V – long chain alcohols and hydrocarbons)
- Sensor # 23 (S – short chain alcohols and ketones)
  (V – long chain alcohols and hydrocarbons)
- Sensor # 24 (S – short chain alcohols and ketones)
  (V – long chain alcohols and hydrocarbons)

Chemical and physical analyses

Lipid oxidation was monitored using the thiobarbituric acid reactive substances (TBARS) method reported by Zipser and Watts (1962). Color changes were evaluated using a Hunterlab Labscan instrument (Hunterlab Labscan, Model LS 5100). The CIE L* (lightness), CIE a* (redness/greenness), and the CIE b* (yellowness/blueness) were obtained using a 25 mm port size with a 10° observer and an A illuminant. The instrument was standardized prior to each use by covering the white and black tiles with a piece of the same packaging material used to package the product. Three measurements were taken at different locations of one package of vacuum packaged ham during each day of evaluation. Samples were evaluated for both oxidation (TBARS) and color changes (CIE L*, a*, and b*) on day 1, 5, 10, 15, 31, 45, and 60.

Statistical analysis

The experiment design was a 2x3 factorial treatment design. TBARS values and CIE L*, a*, and b* color values were analyzed using a split plot design with respect to time. The sensory data was evaluated using

the standard errors suggested by Cochran and Cox (1992) to consider the number of panelist used in the double grouping design. All data sets were analyzed using a General Linear Model with the Statistical Analysis System (SAS Institute, Inc. 2000). Least square means and an alpha level of $P < 0.05$ were used to determine significance for all data. The experiment was replicated three times.

Results and Discussion

The effects of rosemary extractives and irradiation treatments on TBARS values of ham are summarized in Table 3.4. The addition of rosemary extractives did not reduce the TBARS values of the hams. This may be due to the low concentration of lipid oxidation compounds present in these products. Statistical analysis indicated that the irradiation treatments increased the TBARS values of vacuum packaged hams in a dose dependent manner. However, the TBARS values of all treatments stayed low (< 0.2 mg of malonaldehyde/1000 g of meat) during the study. Fu and others (1995) reported that the TBARS values of vacuum packed hams were not affected by 2.0 kGy of irradiation. However, Zhao and others (1996) observed a significant increase ($P < 0.05$) in TBARS values of irradiated (1.0 kGy), vacuum packaged pork chops.

Significantly higher ($P < 0.05$) CIE L* values were observed with the addition of rosemary extractives to the hams (Table 3.4). On the other hand, irradiation significantly ($P < 0.05$) decreased the CIE L* values of the irradiated hams when compared with the controls. No differences in L* values were found between hams irradiated with 2.0 kGy and 3.2 kGy. Fu and others 1995 reported that irradiation treatments (0.0-2.0 kGy) did not affect ($P > 0.05$) the Hunter L* values of ham. The CIE a* values significantly decreased ($P <0.05$) with the addition of rosemary extractives, but they were not affected by the irradiation treatments (Table 3.4). Neither antioxidant nor irradiation affected the CIE b* values of the hams (Table 3.4). Fu and others (1995) also reported that medium doses (0.0-2.0 kGy) of ionizing irradiation did not affect the Hunter a*, and b* values of hams.

No order of presentation of meat samples effect was observed during the sensory evaluation of the cold ham (Table 3.9). Sensory evaluations determined that the addition of rosemary extractives did not affect the off-odor, off-flavor, and overall flavor of the cold ham (Table 3.10). Sensory color scores were not affected by the addition of rosemary extractives (Table 3.10) and/or the irradiation treatments (Table 3.11). Irradiation increased the off-odor intensity of the cold hams (Table 3.11). However, the panelists did not detect differences in off-odor

Table 3.4. Means of main effects for lipid oxidation and color analyses of ham[z].

MAIN EFFECTS		OXIDATION	COLOR		
		TBARS	L*	a*	b*
ANTIOXIDANT	0 ppm	0.13	66.10[a]	17.82[b]	13.21
	700 ppm	0.13	67.17[b]	17.28[a]	13.33
	SEM	0.0018	0.27	0.11	0.04
IRRADIATION	0.0 kGy	0.11[a]	67.35[b]	17.52	13.20
	2.0 kGy	0.14[b]	65.99[a]	17.82	13.28
	3.2 kGy	0.15[c]	66.54[a]	17.32	13.34
	SEM	0.0022	0.34	0.13	0.05
ANTIOXIDANT*IRRADIATION	0 ppm + 0.0 kGy	0.11	66.48	17.80	13.21
	0 ppm + 2.0 kGy	0.14	65.16	18.32	13.11
	0 ppm + 3.2 kGy	0.15	66.64	17.35	13.33
	700 ppm + 0.0 kGy	0.11	68.22	17.25	13.19
	700 ppm + 2.0 kGy	0.14	66.82	17.31	13.45
	700 ppm + 3.2 kGy	0.15	66.48	17.30	13.35
	SEM	0.0031	0.47	0.18	0.08

[z] Values within columns, for any given main effect or interaction, with differeng superscripts are significantly different at $P < 0.05$. Means of 63, 42 and 21 numbers for antioxidant, irraidation and antioxidant*irradiation respectively (3 replications, 2 antioxidant levels, 3 irradiation treatments and 7 storage days).

Table 3.5. TBARS values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C						
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	5	10	15	31	45	60
0 ppm	0 kGy	0.119	0.103	0.107	0.100	0.101	0.119	0.134
	2.0 kGy	0.135	0.120	0.130	0.132	0.133	0.153	0.166
	3.2 kGy	0.143	0.139	0.160	0.137	0.154	0.150	0.156
700 ppm	0 kGy	0.098	0.101	0.120	0.105	0.126	0.118	0.118
	2.0 kGy	0.134	0.124	0.140	0.122	0.130	0.144	0.165
	3.2 kGy	0.144	0.142	0.151	0.128	0.147	0.152	0.153
SEM		0.008	0.006	0.006	0.007	0.007	0.006	0.010

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 3 replications, 2 measurements per replications.

Table 3.6. Ham CIE L* values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C						
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	5	10	15	31	45	60
0 ppm	0 kGy	66.36	66.59	66.29	66.35	65.53	67.76	66.45
	2.0 kGy	62.95	66.34	64.76	64.92	65.41	65.06	66.67
	3.2 kGy	66.20	64.14	65.61	68.57	66.96	65.83	69.20
700 ppm	0 kGy	68.48	67.91	68.60	68.14	67.73	67.38	69.29
	2.0 kGy	67.60	65.34	66.52	66.49	66.92	66.96	67.92
	3.2 kGy	65.41	66.27	66.72	66.52	66.03	67.32	67.11
SEM		0.64	0.99	0.78	0.53	0.89	0.67	0.85

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

Table 3.7. Ham CIE a* values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C						
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	5	10	15	31	45	60
0 ppm	0 kGy	17.50	17.58	17.95	18.03	18.16	17.49	17.86
	2.0 kGy	18.84	17.76	18.66	18.23	18.42	18.49	17.86
	3.2 kGy	16.82	18.47	17.64	16.67	17.39	17.77	16.64
700 ppm	0 kGy	17.12	17.39	17.11	17.18	17.44	17.64	16.87
	2.0 kGy	17.01	18.18	17.81	17.65	17.44	17.33	15.74
	3.2 kGy	17.27	17.35	17.10	17.16	17.70	17.14	17.36
SEM		0.39	0.52	0.44	0.21	0.36	0.32	0.62

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

Table 3.8. Ham CIE b* values over storage time[z].

TREATMENTS		DAYS OF REFRIGERATED STORAGE AT 2-4 ^{0}C						
ANTIOXIDANT LEVEL	IRRADIATION DOSE	1	5	10	15	31	45	60
0 ppm	0 kGy	12.70	12.95	13.63	13.34	13.46	13.39	12.97
	2.0 kGy	13.12	12.72	13.21	13.17	13.15	13.47	12.93
	3.2 kGy	13.21	13.61	13.14	13.13	13.36	13.48	13.35
700 ppm	0 kGy	13.05	12.99	13.28	13.12	13.31	13.33	13.21
	2.0 kGy	13.46	13.35	13.42	13.22	13.59	13.44	13.67
	3.2 kGy	13.03	13.28	13.21	13.19	13.42	13.69	13.59
SEM		0.19	0.20	0.25	0.18	0.26	0.25	0.18

[z] Values within columns with differing superscripts are significantly different at $P < 0.05$.
Means of 6 numbers (3 replications and 2 measurements per replication).

Table 3.9. Means of order of presentation of meat samples effect for ham sensory evaluation I[z].

ORDER	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY	OVERALL FLAVOR INTENSITY
1	49.8	47.5	90.9
2	41.1	44.7	85.3
3	40.5	46.3	72.9
4	45.1	49.4	82.2
5	47.7	50.8	74.7
6	45.4	52.3	82.8
SEM	5.1	7.2	8.5

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$

Means are score out of 150 maximum.

Means of 36 numbers (3 replications and 12 panelists).

Table 3.10. Means of antioxidant effects for ham sensory analysis I[z].

ANTIOXIDANT	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY
0 ppm	45.4	48.6
700 ppm	44.5	48.4
SEM	2.9	4.2
ANTIOXIDANT	OVERALL FLAVOR INTENSITY	COLOR INTENSITY
0 ppm	79.1	93.7
700 ppm	83.8	90.8
SEM	4.9	5.5

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.
Means are score out of 150 maximum.
Means of 108 numbers (3 replications, 12 panelists and 3 measurements per panelists).

Table 3.11. Means of irradiation dose effects for ham sensory analysis I[z].

IRRADIATION DOSE (kGy)	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY
0.0	28.5[a]	39.3
2.0	52.9[b]	52.8
3.2	53.5[b]	53.4
SEM	3.6	5.0
IRRADIATION DOSE (kGy)	OVERALL FLAVOR INTENSITY	COLOR INTENSITY
0.0	82.9	89.0
2.0	81.2	93.9
3.2	80.3	93.9
SEM	6.0	5.5

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.
Means are score out of 150 maximum.
Means of 72 numbers (3 replications, 12 panelists and 2 measurements per panelist).

intensity between the irradiated (2.0 and 3.2 kGy) hams. Fu and others (1995) reported that an untrained sensory panel did not detect significant differences ($P > 0.05$) in the odor of irradiated (2.0 kGy) hams. On the other hand, the odor of irradiated (2.0-3.0 kGy) chicken thighs was found to be significantly affected ($P < 0.05$) by a trained sensory panel during a triangle test (Heath and others 1990). No off-flavor was detected between the irradiated and not irradiated cold ham. The overall flavor (flavor produced by the spices) was also not affected by the irradiation treatments.

There was no order of presentation of meat samples effect observed when the ham was evaluated during sensory evaluation II (Table 3.12). An important interaction between heat and irradiation during the off-odor (Figure 3.3) and off-flavor (Figure 3.4) sensory evaluations was observed when the ham samples were presented warm and cold to the panelists. Heat decreased the off-odor and off-flavor intensities of the irradiated ham. However, the panelists detected differences in off-odor and off-flavor between the irradiated (3.2 kGy) and not irradiated warm and cold samples during sensory evaluation II. Heat did not affect the panelists' scores for the overall flavor intensity (flavor of the blend of spices) of the ham during sensory evaluation II.

The effect of heat and irradiation on the Aroma Scan values are summarized on Table 3.13. Heat had no significant effect ($P > 0.05$) on the Aroma Scan values. However, these results indicate that the concentration of lipid oxidation compounds such as alcohols, hydrocarbons, and ketones detected by the Aroma Scan significantly decreased ($P < 0.05$) when a dose of 3.2 kGy was applied to the ham. No data has been previously reported on the effect of heat and irradiation on the Aroma Scan values of ham. However, other researchers detected an increase in the concentration of hydrocarbons (Hwang 1999) and total volatiles (Ahn and others 1998) with gas chromatography analysis.

Conclusions

The addition of rosemary extractives produced some color changes in the hams according to the CIE values, however, these color changes were not observed by the sensory panelists. The higher TBARS values in the irradiated hams do not represent a practical concern since the values were still very low during the 60 days storage period. On the other hand, more research is needed to find treatment combinations that will minimize the off-odors and off-flavors produced in irradiated hams.

Table 3.12. Means of order of presentation of meat samples effect for ham sensory evaluation II[z].

ORDER	OFF-ODOR INTENSITY	OFF-FLAVOR INTENSITY	OVERALL FLAVOR INTENSITY
1	39.2	39.0	86.8
2	45.2	43.3	90.9
3	38.8	47.8	77.9
4	40.3	37.2	73.6
SEM	3.0	2.9	6.3

[z] Values within column, for any given sensory attribute, with differing superscripts are significantly different at $P < 0.05$.
Means are score out of 150 maximum.
Means of 36 numbers (3 replications and 12 panelists).

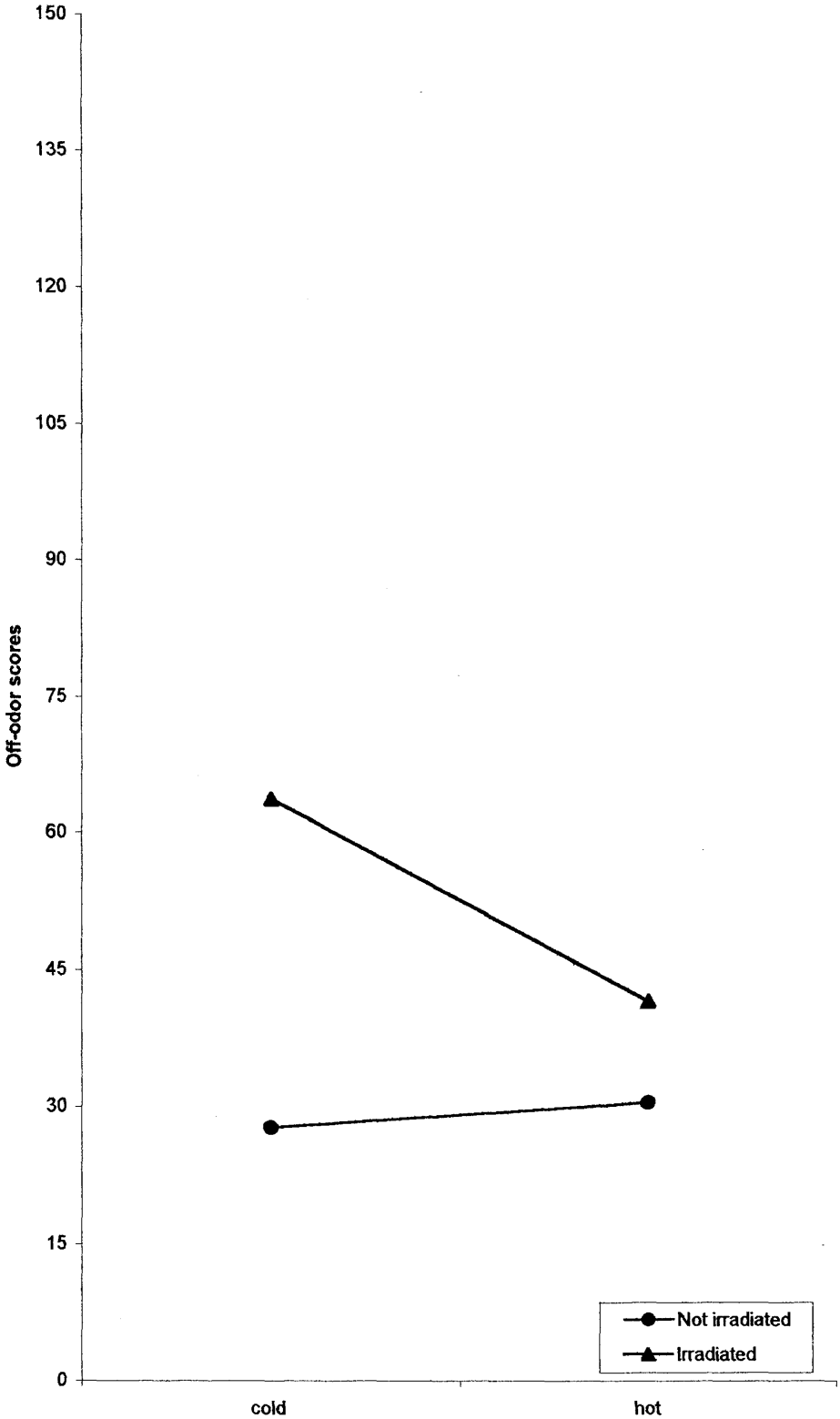

Figure 3.3. Interaction between heat and irradiation for off-odor intensity.

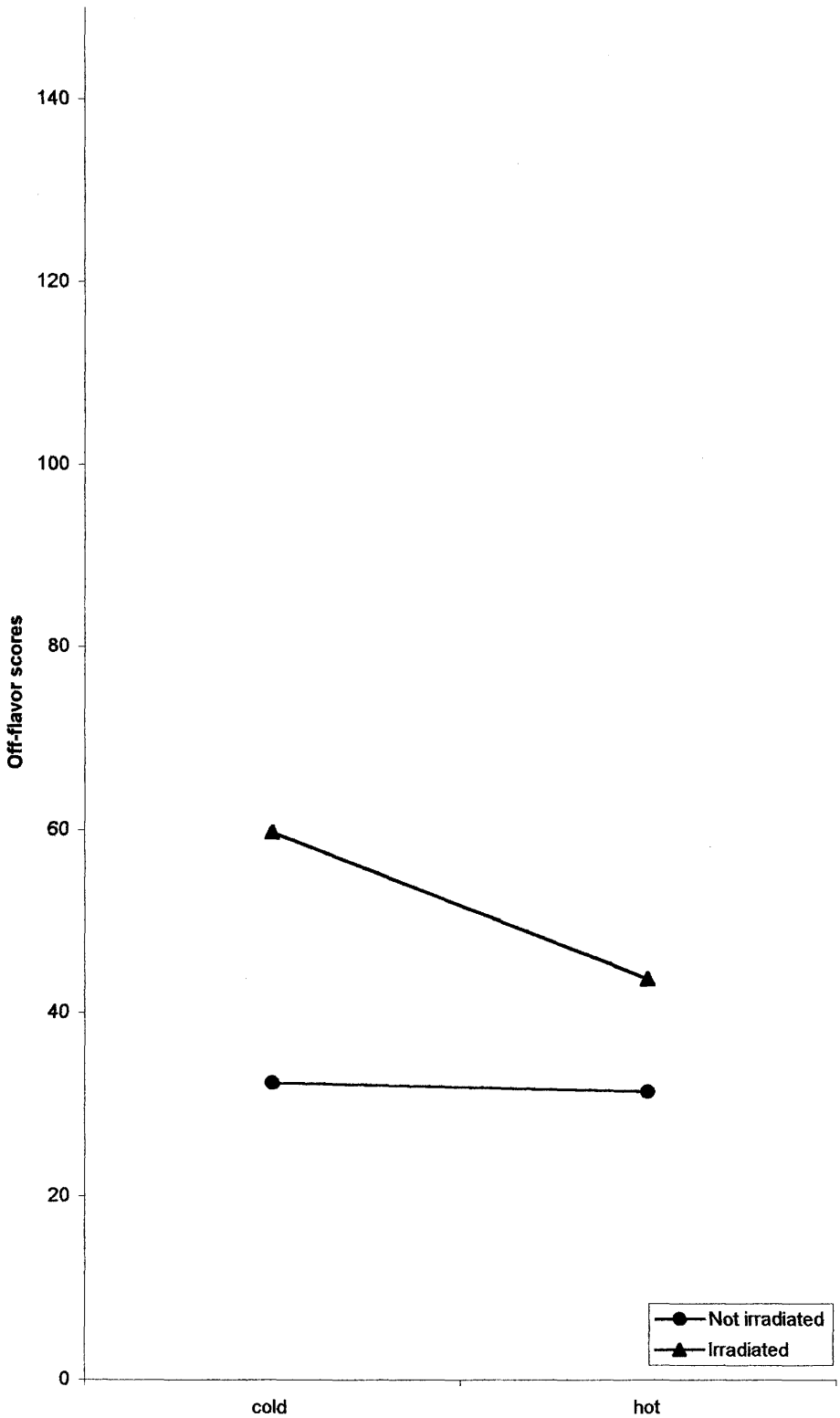

Figure 3.4. Interaction between heat and irradiation for off-flavor intensity.

Table 3.13. Means of main effects for aroma scan analysis of ham[z].

MAIN EFFECTS		AROMA SCAN SENSORS			
		SENSOR # 17	SENSOR # 22	SENSOR # 23	SENSOR # 24
HEAT	NO	3.26	2.92	3.03	3.26
	YES	3.31	2.95	3.08	3.31
	SEM	0.02	0.01	0.02	0.02
IRRADIATION	0.0 kGy	3.33^{bc}	2.97^{bc}	3.10^{bc}	3.33^{bc}
	2.0 kGy	3.29^{ab}	2.94^{ab}	3.06^{ab}	3.29^{ab}
	3.2 kGy	3.23^{a}	2.90^{a}	3.01^{a}	3.24^{a}
	SEM	0.02	0.01	0.02	0.02
HEAT*IRRADIATION	NO + 0.0 kGy	3.32	2.97	3.1	3.33
	NO + 2.0 kGy	3.24	2.91	3.02	3.25
	NO + 3.2 kGy	3.2	2.89	2.99	3.22
	YES + 0.0 kGy	3.33	2.97	3.11	3.23
	YES + 2.0 kGy	3.35	2.97	3.11	3.33
	YES + 3.2 kGy	3.26	2.92	3.04	3.27
	SEM	0.03	0.02	0.03	0.03

[z] Values within columns, for any given main effect or interaction, with differing superscripts are significantly different at $P < 0.05$.
Means of 45, 30, and 15 numbers for heat, irradiation, and heat*irradiation respectively (3 replications, 2 heat levels and 3 irradiation doses).

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CHAPTER 4. GENERAL CONCLUSIONS

General Discussion

This section summarizes the results and discussion sections of the two manuscripts included in this thesis. The parameters evaluated during both of these research projects were lipid oxidation (TBARS), color changes (CIE L*, a*, and b*), and sensory characteristics such as color, off-odor, off-flavor, and overall flavor intensities. The results found during these studies will be compared with those previously reported in the literature.

Rosemary extractives significantly ($P < 0.05$) reduced the formation of lipid oxidation compounds (TBARS values) of the turkey roll. However, the rosemary extractives did not alter the lipid oxidation process of the ham. Barbut and others (1985) observed a significant ($P < 0.05$) reduction in TBARS values of turkey sausages when 20 ppm of rosemary was added to the product and stored for 15 days at 4°C. On the other hand, Liu and others (1992) reported that a combination of rosemary and sodium tripolyphosphate did not slow down lipid oxidation in restructured pork steaks stored at 4°C.

Irradiation showed no effect on the TBARS values of the turkey roll, but it significantly increased ($P < 0.05$) the TBARS values of the ham in a dose dependent manner. However, the TBARS values of the irradiated ham stayed below 0.2 milligrams of malonaldehyde/ 1000 grams of meat during a 60 days storage period. According to Ahn and others (1998) and Fu and others (1995), irradiation produced no significant ($P < 0.05$) changes in TBARS values of turkey breast and ham, respectively.

Rosemary extractives did not affect the CIE L*, a*, and b* of the turkey roll. The ham CIE L* values increased ($P < 0.05$) with the addition of 700 ppm of rosemary extractives. Rosemary significantly ($P < 0.05$) decreased the CIE a* color values of the ham.

The CIE L* values of the turkey roll were not affected by the irradiation treatments. The opposite is true in the ham where the CIE L* values were significantly higher ($P < 0.05$) when the product was treated with irradiation. Fu and others (1995) reported that irradiation (1.8 kGy) treatments did not affect the L* values of ham. However, other authors (Lambert and others 1992; Zhao and others 1996) found higher ($P < 0.05$) L* values in irradiated pork. Irradiation significantly increased the CIE a* values of the turkey roll, but it produced no changes on the CIE a* values of the ham. This increase in a* values has also been observed in irradiated,

fresh turkey (Nanke and others 1998). No changes in a* values of irradiated (1.8 kGy) ham have been reported by other authors (Fu and other 1995). The CIE b* values were significantly decreased ($P < 0.05$) by irradiation in the turkey roll, but not in the ham. A significant increase ($P < 0.05$) in b* values of fresh pork loins (Lambert and others 1992) and turkey (Nanke and others 1998) have been observed by other authors. Fu and others (1995) reported that irradiation did not affect the b* values of ham.

A trained sensory panel observed a significant increase in the pink color intensity of the irradiated turkey roll. However, the panelists did not observe any color difference due to the addition of rosemary extractives and/or irradiation in the ham. Sensory panelists detected a significant increase in pink color of irradiated, fresh pork and turkey (Nanke and others 1998). Previous studies have also shown that the ham sensory color scores are not affected by irradiation treatments (Fu and others 1995).

Irradiation increased the off-odor intensity of both the turkey roll and ham. The off-flavor intensity was also affected by the irradiation treatments in the turkey roll, but not in the ham, when the products were presented cold (25°C) to the panelists. Heat did not decrease the off-odor and off-flavor of the irradiated turkey roll. However, a reduction in the off-odor and off-flavor intensities of the irradiated (3.2 kGy) ham was detected by the sensory panelists when the product was evaluated warm and cold. Other authors have also found that irradiation increased the odor of ham (Hansen 1966) and frankfurters (Terrell and others 1981).

An Aroma Scan Analysis indicated that heat did not affect the Aroma Scan values. The Aroma Scan analysis detected a significant ($P < 0.05$) reduction in the concentration of hydrocarbons, alcohols, and ketones in the irradiated (3.2 kGy) ham when compared with the control.

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